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Science, Engineering & Technology Los Alamos Judicial Science School

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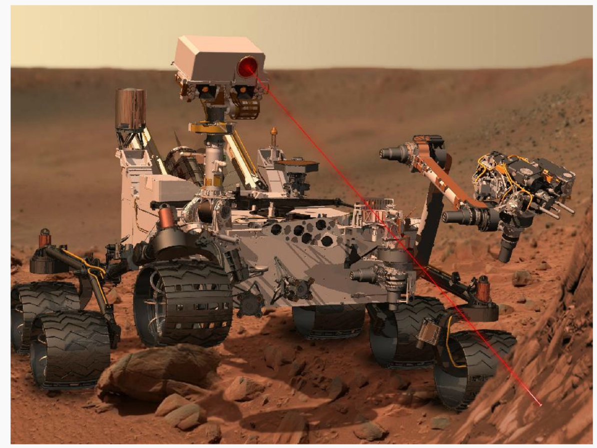
Learning Objectives

- Define science, engineering and technology
- Understand the relationship between science, engineering and mathematics
- Introduce the concepts of length and time scales
- Discuss technology maturity

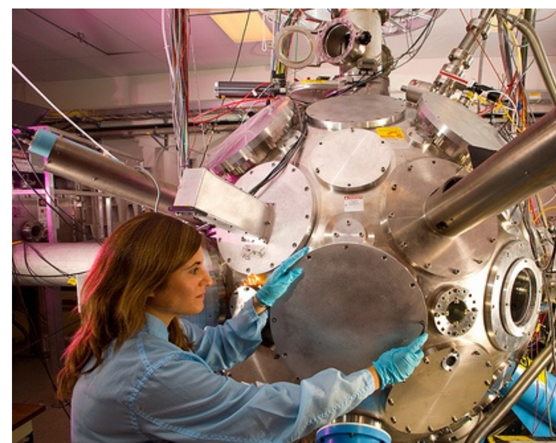


$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0 \qquad (1)$$

$$\rho \frac{\partial \mathbf{v}}{\partial t} + (\rho \mathbf{v} \cdot \nabla)\mathbf{v} = -\nabla \left(P + \frac{B^2}{8\pi} \right) - \rho \nabla \Phi + \left(\frac{\mathbf{B}}{4\pi} \cdot \nabla \right) \mathbf{B} \qquad (2)$$

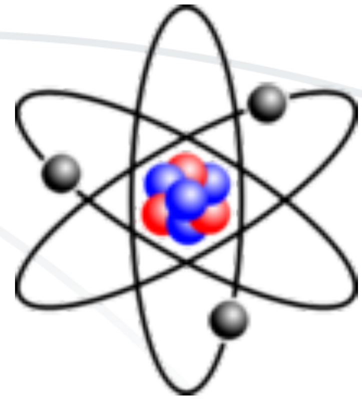
$$\frac{\partial \rho \epsilon}{\partial t} + \nabla \cdot (\rho \epsilon \mathbf{v}) = -P \nabla \cdot \mathbf{v} \qquad (3)$$

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{v} \times \mathbf{B}) \qquad (4)$$



What is science?

- **Science** is the process of understanding the world in which we exist (past, present and future).
- This understanding is gained by
  - **Observation** of natural phenomena
  - Performing **experiments** where we recreate observed behavior under controlled conditions
  - The development of **models** that predict an observation (either natural occurring or experimental) based on initial conditions and some specified inputs
- Science can also refer to the body of knowledge developed by scientists.



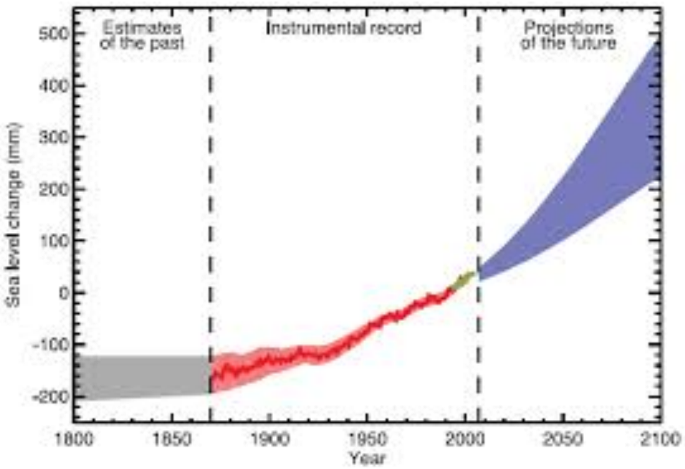
Small

Length scale of the observation

Large

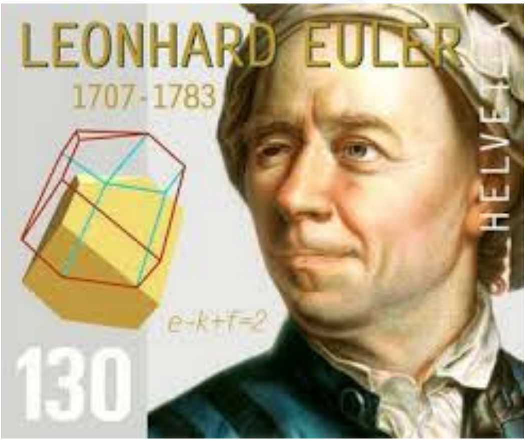
Examples of science

- **Observation**: Paleontologists examining the geologic layers above fossils to ascertain the reason for mass extinctions.
- **Experiments**: Biochemists placing carbon, nitrogen, hydrogen and oxygen in a controlled environment and apply an electric pulse (simulated lightning) to study the origins of life.
- **Modeling**: Climatologists develop computer simulations that predict the rise in sea level based on current climate conditions and the amount of carbon being added to the atmosphere.

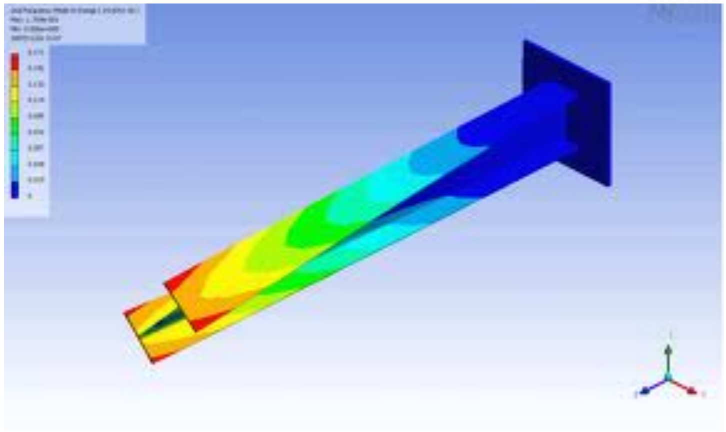


What is a scientific theory?

- A scientific **theory** is an explanation of some observed physical phenomena
  - **Theory of evolution**: controversial, not universally accepted
  - **Euler-Bernoulli beam theory**, well accepted because there is a tremendous amount of experimental evidence to support this theory!



Daniel Bernoulli
1700-1782



What is engineering?

- **Engineering** is the process of transforming basic scientific knowledge into tools and using those tools to solve problems
  - Hardware (dental X-ray machine)
  - Software tools (simulate car crash dynamics)
- **Engineering** uses the tools available today to solve current problems
- **Engineering Research** focuses on developing new tools based on evolving scientific discovery

Examples of engineering

- The development of the internet: a complex integration of computers, telecommunications and software
- The development of the global positioning systems (GPS)
- The design of the interstate highway system
- Predicting the maximum load that an aircraft wing can withstand

What is the relationship between science and engineering?

- As previously mentioned, science provides the basic understanding of physical phenomena and engineering transforms that understanding into tools.
- New tools (e.g. telescopes, particle accelerators, magnetic resonance imaging (MRI)) allow the scientist to make more detailed observations and gain further understanding of the physical world.

Hubble Telescope

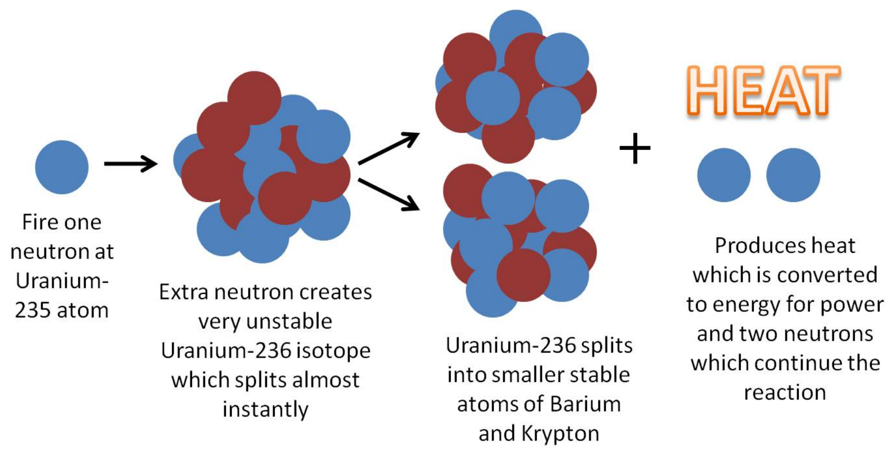
Images from the Hubble Telescope

What do we mean by the term "technology"

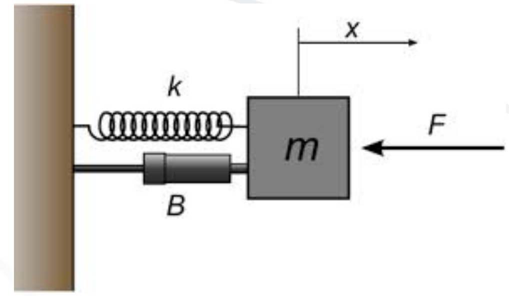
- **Technology** is the tools and knowledge that result from science and engineering
- We can think of technology in many ways
  - Objects (tools, instruments, infrastructure)
  - Knowledge (materials behavior)
  - Processes (manufacturing, chemical)

Examples of technology

- Production and distribution of electricity
  - Objects: nuclear power plant, transmission lines, sub-stations
  - Knowledge: nuclear fission
  - Processes: enrichment of natural occurring uranium

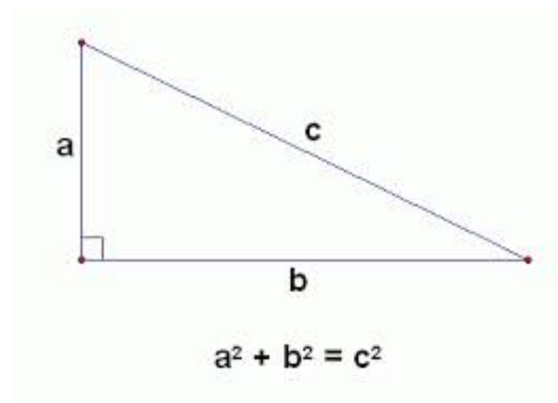


Where does mathematics fit in?



$$m\ddot{x} + b\dot{x} + kx = F$$

- Informally, **mathematics** is the “language” of science and engineering.
- Dictionary definition: “*The study of the measurement, properties, and relationships of quantities and sets, using numbers and symbols.*”
- Most science and engineering models are expressed in terms of mathematical equations.
- Experimental results are quantified in terms of mathematics.
- Mathematics is not a science. The scientific method is not employed in the develop mathematics.
- Instead, mathematics is built upon **axioms** (e.g. rules) that are accepted without proof:
  - **Commutative Axiom for addition: a+b=b+a**
- Based on these axioms, other mathematical relations are defined in terms of **theorems,** which are **proved** according to a defined logic process.



Pythagorean theorem

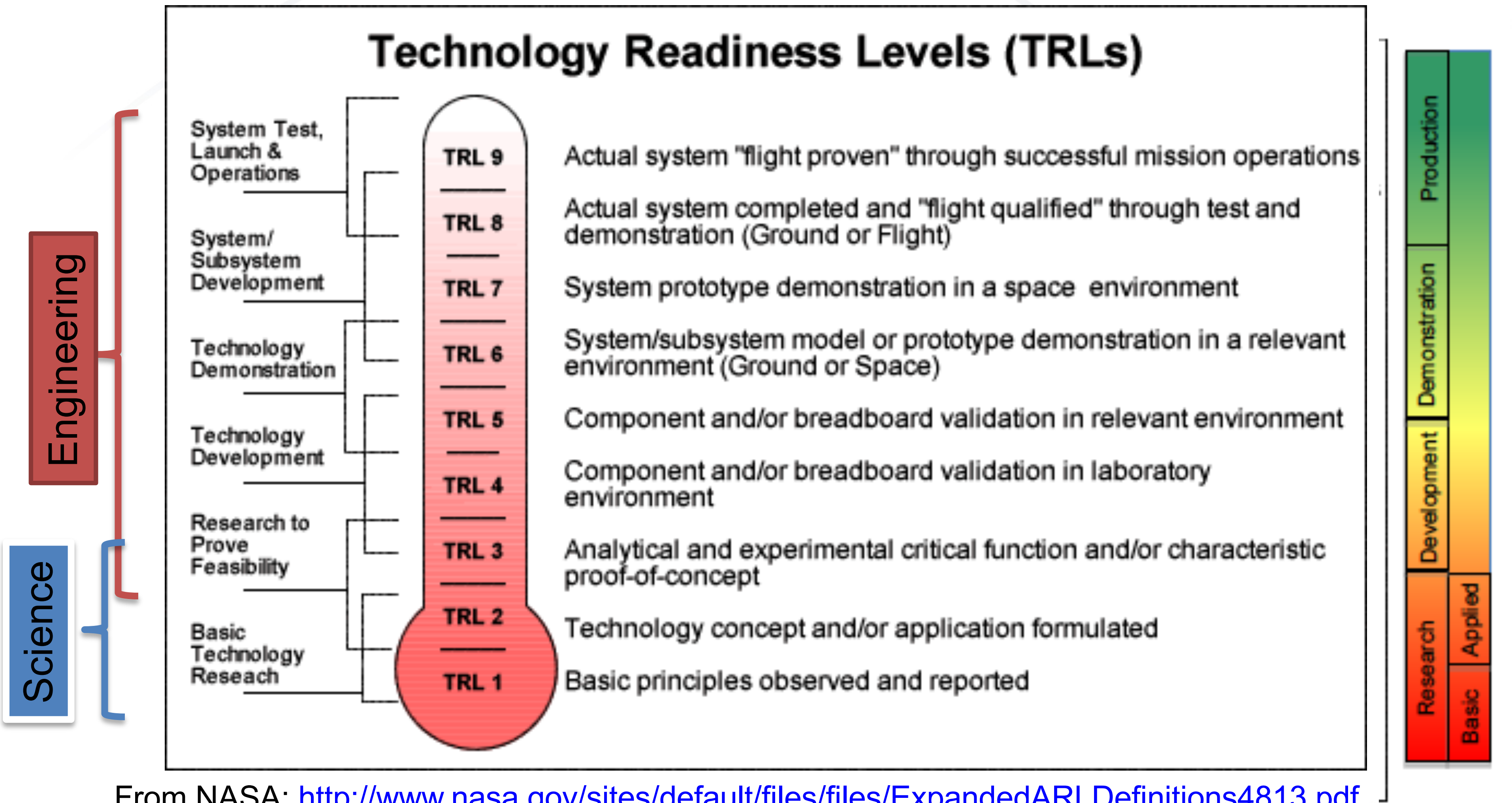
The concept of length and time scales

- The terms **length** and **time scales** refer to the units of length and time that are needed to describe a physical phenomena.
- Some examples of length scales
  - **Angstroms** (one ten-billionth (10^{-10}) of a meter)
  - **Meters** (base unit of length)
  - **Light year** (approx. 9.5 quadrillion (10^{15}) meters)
- Some examples of time scales
  - **Shake** 10^{-8} seconds
  - **Seconds** (base unit of time)
  - **Galactic year** (time our solar system need to orbit the galaxy) approx. 2.3×10^{8} years

Discussion: Science, Engineering, Technology and Mathematics

- Based on these definitions, would you consider your primary care physician a ***Scientist*** or ***Engineer***?
  - Scientist
  - Engineer
  - Both
  - Neither
- What do you consider the mathematical (including statistics) acumen of a typical jury member (in terms of school grade level)
  - Functionally illiterate
  - 6th Grade
  - 9th Grade
  - HS graduate or above
- What challenges does this level of mathematical competency pose for expert witness testimony?
- What new ***technologies*** are you seeing in your courts?

How do we define technical maturity

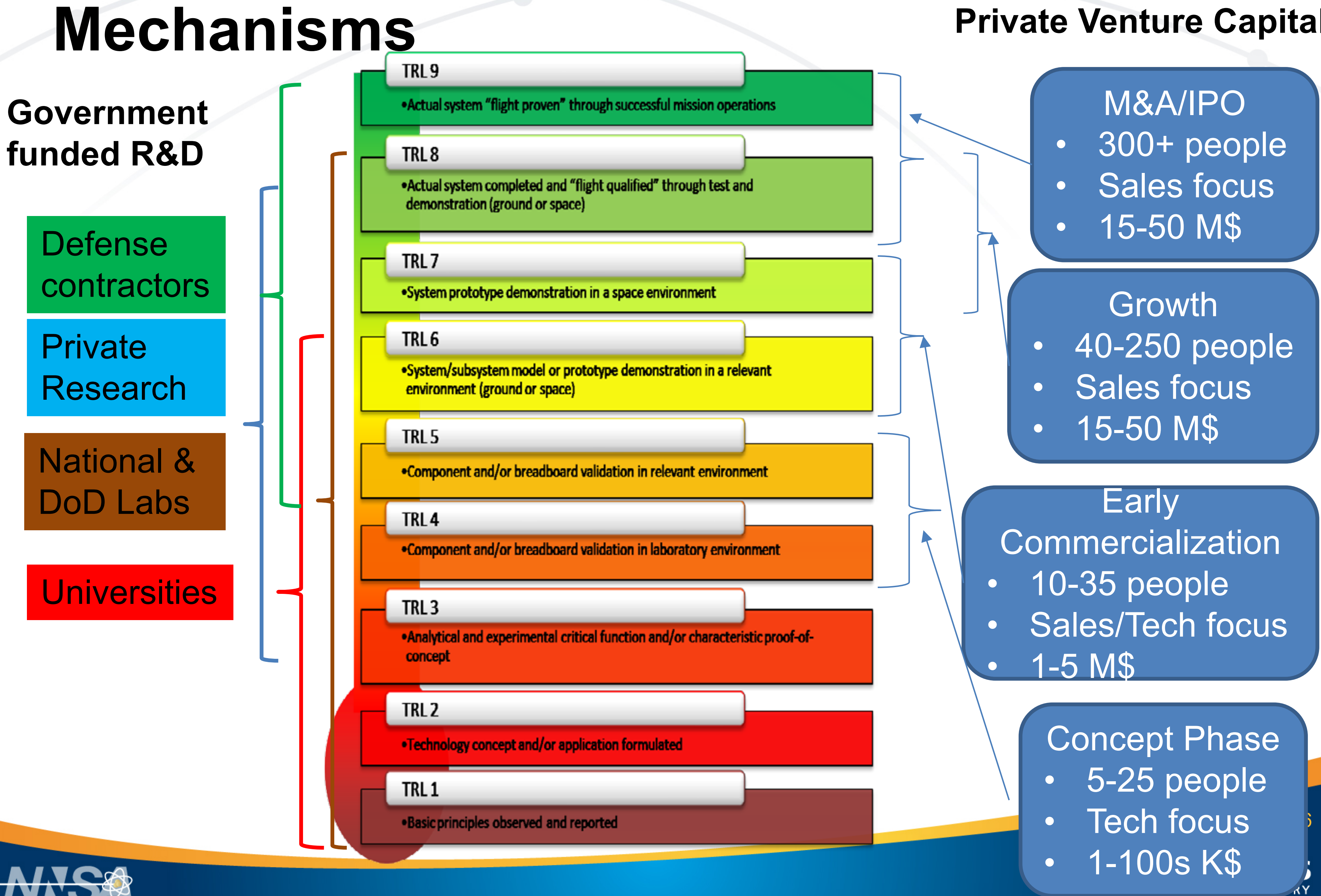


From NASA: http://www.nasa.gov/sites/default/files/files/ExpandedARLDefinitions4813.pdf
Also see: https://en.wikipedia.org/wiki/Technology_readiness_level

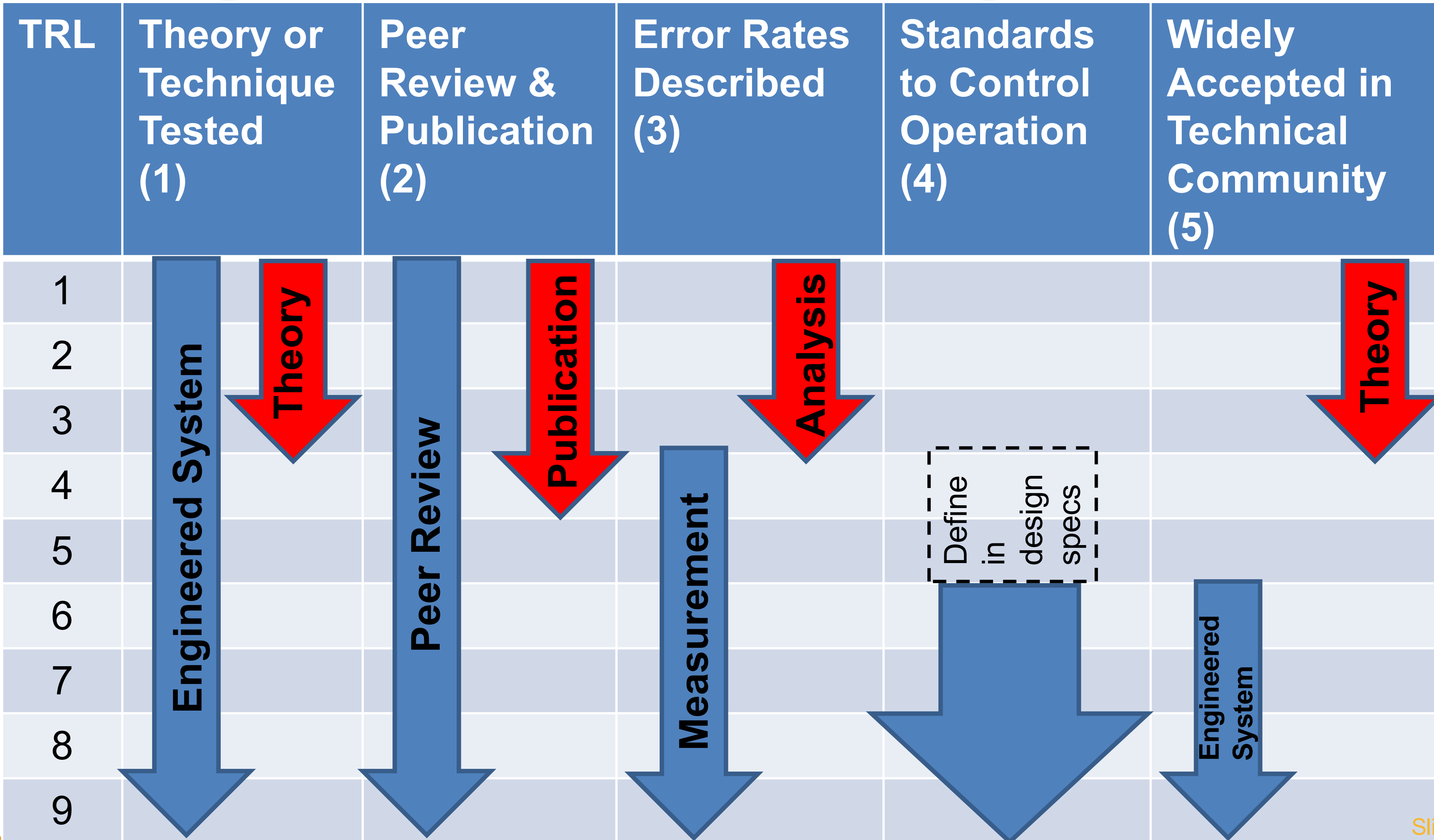
TRL Level Descriptors

TRL Level	Descriptions
1	Basic Research (Baseline ideas)
2	Concept formulation, Still Speculative (Invention)
3	Analytical or Experiment Proof of Concept (Viability Established)
4	Component validation in lab, system not integrated (Prototype/Plan)
5	Component validation in intended environment (Potential Determined)
6	System prototype demonstrated in intended environment (Potential Demonstrated)
7	System prototype demonstrated in actual environment (Functionality Demonstrated)
8	System Completed and Tested, (Functionality Proven)
9	System proven in use (Sustained Use)

Maturity of Technology and Funding Mechanisms



Relating TRLs to Daubert Factors



Discussion – Technology Readiness Levels

- Based on the definitions presented, with what level of certainty can one assign a technology readiness level?
  - The majority of people will assign the same readiness level
  - Most people will assign a readiness level to within one of two sequential levels.
  - People will assign vastly different readiness levels (three or more levels difference).
- Is the concept of technology readiness levels excepted internationally?
  - Yes.
  - No, this is only used in the U.S.
  - Used in some countries, but not used by a majority of countries.
- Do you see technology at readiness levels 1 and 2 in your courts?
  - Yes.
  - No.
  - Not sure.

Questions to consider when evaluating technology

Daubert Factor

- **Reliability**
  - What is the maturity level of this technology?
    - What makes you think it's at this maturity level?

    1-5
  - What forms of peer review have been applied to this technology?
    - What forms of peer review have been used with this specific application?
    - Has there been independent reproduction of the experimental results this technology is based upon?
    - What are the potential sources of variability that can influence these experimental results?

    2,5
  - Are there codes or standards governing the use of this technology?
    - If so, have they been adhered to in this application?

    4,5
  - What are the assumptions that this technology is based on and what are the limits of applicability? 1,3
  - Is the proposed technology necessary and sufficient to address this specific application? 1,3,5
- **Fit for Purpose**
  - What are the competing technologies or alternate approaches and why was the proposed technology chosen over these alternatives?
    - What is the competing technology maturity level?
    - What peer review had been applied to the competing technology?
    - What are assumptions and limitations associated with the competing technology?

    1-5
  - Has there been a direct comparison between the proposed technology and competing technology for the application under consideration? 2-5
  - For the application under consideration, how often is the competing technology used relative to the proposed technology? 5
  - What are the assumptions that the alternative technology is based on and what are the limits of its applicability (relative to proposed technology)? 1,3
  - Are the competing technologies also necessary and sufficient to address this specific application? 1,3,5

Glossary

- Science - the process of understanding the world in which we exist
- Observation – gathering of data about the natural world
- Experiment - recreating observed behavior under controlled conditions
- Model - idealized (physical or mathematical) representation of a physical system
- Initial conditions – the value of a system parameter(s) at a designated initial time
- Theory - an explanation of some observed physical phenomena
- Engineering - process of transforming basic scientific knowledge into tools and using those tools to solve problems
- Technology - the tools and knowledge that result from science and engineering
- Mathematics - The study of the measurement, properties, and relationships of quantities and sets, using numbers and symbols
- Axioms – an accepted truth or principle
- Theorems – a mathematical statement that is proved by an established reasoning procedure based on previously proven theorems and accepted truths (axioms)
- Scientific Method - a systematic way to answer scientific questions by making observations, hypotheses and doing experiments
- Technology Readiness Levels – a method for assessing technology maturity
- Prototype – the first fully-function system or device used to demonstrate that a technology will work as intended.
- Breadboard – synonym for prototype, often used in the context of prototyping electronic circuits
- Proof of Concept – a demonstration that and idea or system is feasible
- Peer Review – the evaluation of work by people knowledgeable about that work and usually independent from the producers of the work.
- Error rates – frequency that errors occur